EFSUMB Newsletter

European Federation of Societies for Ultrasound in Medicine and Biology

New Technology

Demonstration of a Vector Velocity Technique

Abstract: With conventional Doppler ultrasound it is not possible to estimate direction and velocity of blood flow, when the angle of insonation exceeds 60–70°. Transverse oscillation is an angle independent vector velocity technique which is now implemented on a conventional ultrasound scanner. In this paper a few of the possibilities with transverse oscillation are demonstrated.

Keywords: Transverse oscillation, vector velocity, blood flow, velocity estimation, Doppler

Introduction

Velocity and direction of blood flow in vessels is most frequently measured using Doppler ultrasound. The Doppler effect is the frequency change of the sound wave that occurs when either the source of the sound wave or the reflector moves. In the case of medical ultrasound, the reflector is blood cells, primarily red blood cells flowing through the vessel. With the simplest form of Doppler ultrasound (colour flow mapping) it is possible to determine the overall direction of the blood flow through the vessel, and an estimate of the blood flow velocity in the direction of the emitted ultrasound wave, i.e. the axial direction is found. It is therefore only a qualitative technique to visualize flow. By supplementing with Spectral Doppler it is possible to perform angle correction, and achieve a quantitative estimate of the velocity of the blood flow in the presumed correct direction, i.e. along the blood vessel.

One of the limitations of the Doppler technique is the drop in frame rate that occurs when scanning in du- and triplex mode (combining B-mode, Doppler and Spectral Doppler). A low frame rate makes it impossible to visualize rapid changes in the blood flow. Another limitation is the angle dependency and need for manual angle correction. Combining the Doppler equation with the Cosine function which is used for angle correction, the true velocity v, i.e. along the vessel, is given by $v = \frac{v_z}{\cos\theta} = \frac{f_d c}{2 f_0 \cos\theta}$

where v_z is the axial velocity, f_d is the received frequency, c is the velocity of ultrasound in human tissue, f_0 is the frequency of the emitted ultrasound wave and θ is the angle between the ultrasound wave and the direction of the blood flow. From this equation it can be seen that at 90° insonation, the Doppler function is not applicable since $\cos 90 = 0$. Additionally $\cos\theta$ drops excessively steep as the angle of insonation exceeds 60–70°, and it is therefore essential to keep the angle below 60–70° to achieve a valid estimate of the velocity [1]. The angle correction can be done manually by tilting the transducer or electronically by adjusting the direction of the ultrasound wave, but either way the operator has to perform the correction based on the B-mode image. This correction procedure is difficult to apply to blood vessels with complex geometry (branching, curving, stenoses, dilatations, etc) and furthermore the velocity estimation is based on the assumption that the flow is laminar. The complex geometry and passage of e.g. valves creates complex flow profiles [2], which are not possible to visualize with Spectral Doppler, and generates misleading velocity estimations. In these vessels with complex flow arteriosclerosis is predilected, and as much information as possible is wanted [3–5].

The angle dependency have been tried circumvented in several ways, e.g. using two ultrasound beams [6], speckle tracking [7], plane wave excitation [8, 9] and transverse oscillation [10]. The latter is demonstrated in this paper.

Examples

The scans in this short report were performed on three voluntary, healthy, male subjects at age 33, 34 and 37 by an experienced radiologist. Scan sequences of the common carotid artery, jugular vein, carotid bulb, femoral vein, femoral artery and the abdominal aorta have been acquired. The study is approved by The Danish National Committee on Biomedical Research Ethics.

With transverse oscillation the conventional Doppler method is used to estimate the axial velocity component v_z. By manipulating the receive apodization the transverse velocity component v_x is found simultaneously and the true velocity and direction of the blood flow is calculated as a vector.

Transverse oscillation is proposed by Jensen and Munk [10] and has been tested in computer simulations and with flow-phantoms by Jensen and Udesen [11,12]. Udesen et al. have tested the technique in-vivo [13] and Hansen et al. have done in-vivo validation of transverse oscillation against MRI angiography with a high correlation between the modalities (R 0.91) [14]. Both of the in-vivo studies were conducted with the experimental scanner RASMUS at The Technical University of Denmark, Center for Fast Ultrasound Imaging.

Transverse oscillation is now implemented in a conventional ultrasound scanner (Pro Focus 2202 UltraView, BK Medical), which is equipped with a conventional Linear Array Transducer (8670, BK Medical). UltraView displays the velocity and direction of the blood flow with coloured pixels, very similar to colour flow mapping,

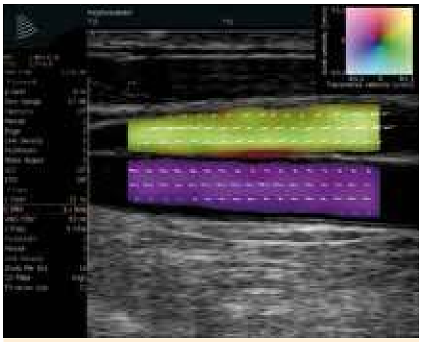

Fig. 1 Volunteer 1. Scan on the longitudinal axis of the common carotid artery (lower vessel) and the jugular vein (upper vessel) illustrating simple bidirectional blood flow.

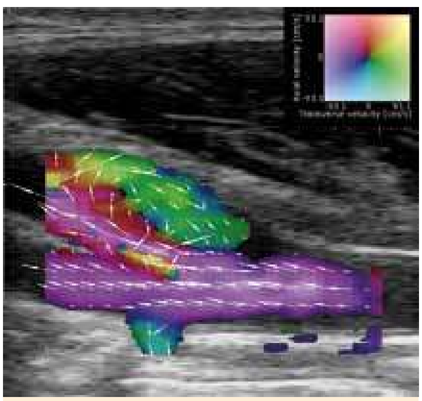

Fig. 2 Volunteer 3. Scan on the longitudinal axis of the carotid bifurcation showing the carotid bulb. The carotid bulb is a dilation of the internal carotid artery (upper vessel) containing baroreceptors involved in regulating blood pressure. Because of the changing diameter of the vessel a vortex is formed in the carotid bulb. It appears at the top of the figure, where the green pixels illustrate retrograde flow.

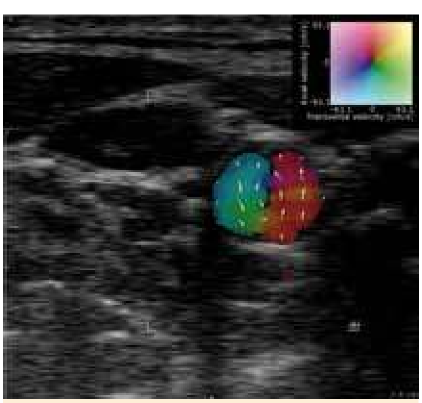

Fig. 3 Volunteer 2. Scan on the transversal axis of the common carotid artery illustrating secondary flow, i.e. the phenomenon that blood flowing antegrade through a vessel, simultaneously rotates around a central axis in the vessel. Appears primarily in systole and has previously only been shown using MRI [15,16] or offline experimental ultrasound scanning with the Plane Wave Excitation technique [17].

this is supplemented with multiple arrows of adjustable size which is superimposed real-time on the colour flow map. These arrows illustrate momentary changes in blood flow direction and velocity throughout the colour flow mapped area of the blood vessel. It is thus possible to demonstrate different flow phenomena which have never before been shown real-time on a conventional ultrasound scanner.

The sonograms presented in **Figs. 1–6** were chosen from the recorded ultrasound sequences. The figures are screen shots and there has been no offline processing. Please note the angle of insonation.

Discussion

Using UltraView it is now possible to perform a real-time angle independent visualization of blood flow direction and estimation of velocity. Furthermore the velocity estimation is made operator independent, now the need for angle correction is gone. In previous studies of Spectral velocity estimation it has been shown that e.g. the manual angle correction is a cause of erroneous velocity estimation. Hoskins found 10–100 % error of the estimation at maximum velocity assuming all flow is laminar [18]. Since this is not the case, cf secondary flow, the use of Spectral technique for velocity estimation is further compromised.

As previously mentioned, transverse oscillation has been validated against MRI angiography, but even this modality has limited accuracy when estimating velocity. Furthermore the estimate is generated as an average of several heartbeats, which conceals any irregularities of the individual heartbeat [16, 19]. With UltraView it is not possible to estimate the secondary flow when scanning on the longitudinal axis of a vessel, since it is only a 2D scanning, but at Technical University of Denmark, Center for Fast Ultrasound Imaging a 3D vector flow technique is being developed and implemented on the experimental scanner SARUS [20].

Conclusion

The implementation of transverse oscillation on a conventional ultrasound scanner makes it possible to scan patients and obtain angle independent estimations of blood flow velocity. At the same time it is

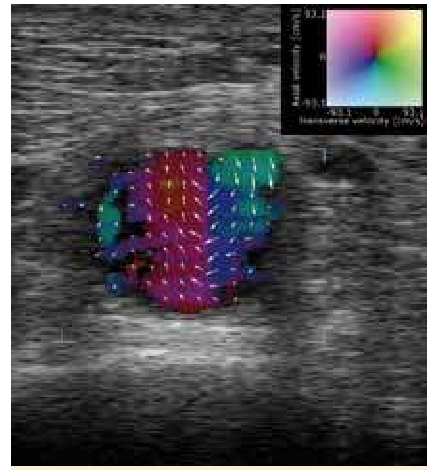

Fig. 4 Volunteer 2. Scan on the transversal axis of the abdominal aorta illustrating the secondary flow.

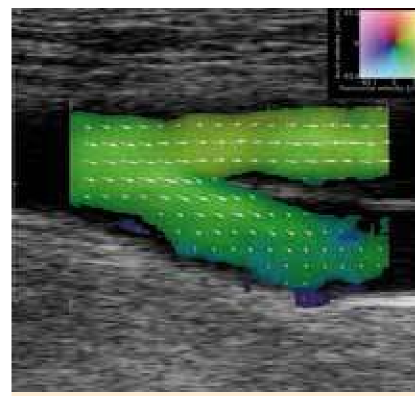

Fig. 5 Volunteer 1. Scan on the longitudinal axis of the femoral bifurcation illustrating simple flow in a branching vessel. No vortex is formed, indicating the vortex in the carotid bulb is related to the increase in vessel diameter rather than the branching.

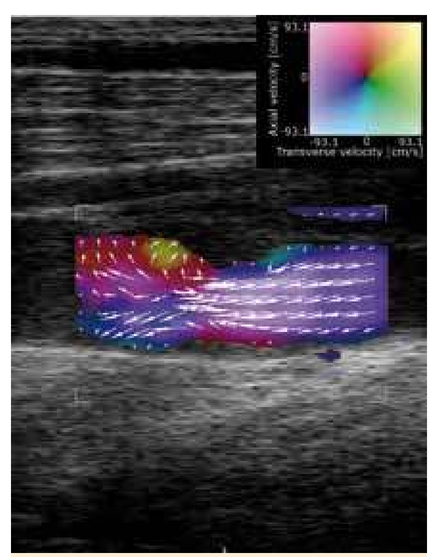

Fig. 6 Volunteer 1. Scan on the longitudinal axis of the femoral vein with disturbed flow at the passage of a venous valve. A vortex is formed in the pocket behind the valve.

possible to illustrate certain flow phenomena real-time in-vivo, which was previously only found offline with the experimental scanner RASMUS [21] or with MRI angiography. The transverse oscillation method also demonstrates that the direction of the blood varies over time and the angle is not a precise representation of the flow direction in a cross section of the vessel. The information acquired with transverse oscillation can hopefully help improve the diagnostic and prognostic studies of both healthy and sick individuals. E.g. generating new knowledge about formation and development of arteriosclerotic plaques, insufficient or stenotic heart valves, more factors leading to high blood pressure, deep venous thrombosis etc. The scanner is the first of its kind, which naturally leads to some limitations. Continuous work is being done to minimize this, but further studies with volunteers and patients are needed, as well as development of the technique.

References

1 Jensen JA. (1996) Estimation of blood velocities using ultrasound: A signal processing approach. New York: Cambridge University Press
2 Hoskins PR. (1997) Peak velocity estimation in arterial stenosis models using colour vector Doppler. Ultrasound Med Biol 23(6):889–897
3 Birchall D, Zaman A, Hacker J, Davies G, Mendelow D. (2006) Analysis of haemodynamic disturbance in the atherosclerotic carotid artery using computational fluid dynamics. Eur Radiol 16(5):1074–1083
4 Cheng C, Tempel D, van Haperen R, van der Baan A, Grosveld F, Daemen MJ, Krams R, de Crom R. (2006) Atherosclerotic lesion size and vulnerability are determined by patterns of fluid shear stress. Circulation 113(23):2744–2753
5 Richter Y, Edelman ER. (2006) Cardiology is flow. Circulation 113(23):2679–2682
6 Fox MD. (1978) Multiple crossed-beam ultrasound Doppler velocimetry. IEEE Trans Son Ultrason 25(5):281–286
7 Trahey GE, Allison JW, von Ramm OT. (1987) Angle independent ultrasonic detection of blood flow. IEEE Trans Biomed Eng 34(12):965–967
8 Udesen J, Gran F, Hansen KL, Jensen JA, Thomsen C, Nielsen MB. (2008) High framerate blood vector velocity imaging using plane waves: simulations and preliminary experiments. IEEE Trans Ultrason Ferroelec Freq Contr 55(8):1729–1743
9 Udesen J, Gran F, Hansen KL, Jensen JA, Nielsen MB. (2007) Fast blood vector velocity imaging: Simulations and preliminary in-vivo results. IEEE Ultrasonics Symp:1005–1008
10 10. Jensen JA, Munk P. (1998) A new method for estimation of velocity vectors. IEEE Trans Ultrason Ferroelec Freq Contr 45:837–851
11 Udesen J, Jensen JA. (2003) Experimental investigation of transverse flow estimation using transverse oscillation. Proc IEEE Ultrasonics Symp:1586–1589
12 Udesen J, Jensen JA. (2006) Investigation of transverse oscillation method. IEEE Trans Ultrason. Ferroelec Freq Contr 53:959–971
13 Udesen J, Nielsen MB, Nielsen KR, Jensen JA. (2007) Examples of In-vivo Blood Vector Velocity Estimation. Ultrasound Med Biol 33(4):541–548
14 Hansen KL, Udesen J, Thomsen C, Jensen JA, Nielsen MB. (2009) In-vivo Validation of a Blood Vector Velocity Estimator with MR Angiography. IEEE Trans Ultrason Ferroelec Freq Contr 56(1):91–100
15 Lee KL, Doorly DJ, Firmin DN. (2006) Numerical simulations of phase contrast velocity mapping of complex flows in an anatomically realistic bypass graft geometry. Med phys 33(7):2621–2631
16 Steinman DA, Thomas JB, Ladak HM, Milner JS, Rutt BK, Spence JD. (2002) Reconstruction of carotid bifurcation hemodynamics and wall thickness using computational fluid dynamics and MRI. Magnet Reson Med 47(1):149–159
17 Hansen KL, Udesen J, Gran F, Jensen JA, Nielsen MB. (2009) In-vivo Examples of Flow Patterns With The Fast Vector Velocity Ultrasound Method..Ultraschall in Med 30:471–477
18 Hoskins PR. (1999) A review of the measurement of blood velocity and related quantities using Doppler ultrasound. Proc Inst Mech Eng 213(5):391–400
19 Marshall I, Papathanasopoulou P, Wartolowska K. (2004) Carotid flow rates and flow division at the bifurcation in healthy volunteers. Physiol Meas 25(3):691–697
20 Jensen JA, Hansen M, Tomov BG, Nikolov S, Holten-Lund H. (2007) System architecture of an experimental synthetic aperture Realtime ultrasound system. IEEE Ultrason Symp:636–640
21 Jensen JA, Holm O, Jensen LJ, Bendsen H, Nikolov S, Tomov BG, Munk P, Hansen M, Salomonsen K, Gormsen K, Hansen J, Pedersen HM, Gammelmark K. Ultrasound Research Scanner for Real-time Synthetic Aperture Data Acquisition. In: I E E E Transactions on Ultrasonics, Ferroelectrics and Frequency Control, vol: 52(5), p. 881–891 (2005).

Peter M. Hansen[1], Mads M. Pedersen[1], Kristoffer L. Hansen[1], Michael Bachmann Nielsen[1] and Jørgen A. Jensen[2]
[1] Department of Radiology, Section of Ultrasound, Rigshospitalet, Copenhagen, Denmark
[2] Center for Fast Ultrasound Imaging, Dept. of Elec. Eng., Technical University of Denmark, Lyngby, Denmark

Address for correspondence: Peter Møller Hansen
E-Mail: pdmhansen@gmail.com

Now also in Italian, Spanish

Case of the month

The web statistics show a lot of hits on the Case of the Month coming from outside the English speaking countries. Following a recent meeting in the Publications Committee we decided to try to provide translations for some of the most recent Cases of the Month. In the coming six months we will monitor the hits on the translated pages.

Translation to other languages is also under consideration. If you wish to contribute by translating into your own language please contact the Case of the Month administrator Dr. Paul Sidhu at Paul.Sidhu@efsumb.org.

Michael Bachmann Nielsen